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Geometrical product specifications (GPS) — Filtration —

Part 40: Morphological profile filters: Basic concepts

Spécification géométrique des produits (GPS) — Filtrage —

Partie 40: Filtres morphologiques: Concepts de base

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Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
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Contents

Page

Foreword ... iv
Introduction ... vi
1 Scope ... 1
2 Normative references ... 1
3 Terms and definitions ... 1
4 Basic concepts ... 3
4.1 Minkowski sums ... 3
4.2 Morphological operations ... 4
5 Morphological filters ... 7
5.1 General ... 7
5.2 Fill transform ... 7
5.3 Discrete morphological filters ... 8
5.4 Envelope filters ... 8
5.5 Sampling and reconstruction ... 9
Annex A (informative) Concept diagram ... 13
Annex B (informative) Relationship to the filtration matrix model ... 14
Annex C (informative) Relationship to the GPS matrix model ... 15
Bibliography ... 16

Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 16610-40 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

ISO/TS 16610 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Filtration*:

— *Part 1: Overview and basic concepts*

— *Part 20: Linear profile filters: Basic concepts*

— *Part 22: Linear profile filters: Spline filters*

— *Part 29: Linear profile filters: Spline wavelets*

— *Part 31: Robust profile filters: Gaussian regression filters*

— *Part 32: Robust profile filters: Spline filters*

— *Part 40: Morphological profile filters: Basic concepts*

— *Part 41: Morphological profile filters: Disk and horizontal line-segment filters*

— *Part 49: Morphological profile filters: Scale space techniques*

The following parts are under preparation:

— *Part 21: Linear profile filters: Gaussian filters*

— *Part 26: Linear profile filters: Filtration on nominally orthogonal grid planar data sets*

— *Part 27: Linear profile filters: Filtration on nominally orthogonal grid cylindrical data sets*

— *Part 30: Robust profile filters: Basic concepts*

— *Part 42: Morphological profile filters: Motif filters*

— *Part 60: Linear areal filters: Basic concepts*

— *Part 61: Linear areal filters: Gaussian filters*

— *Part 62: Linear areal filters: Spline filters*

— *Part 69: Linear areal filters: Spline wavelets*

— *Part 70: Robust areal filters: Basic concepts*

— *Part 71: Robust areal filters: Gaussian regression filters*

— *Part 72: Robust areal filters: Spline filters*

— *Part 80: Morphological areal filters: Basic concepts*

— *Part 81: Morphological areal filters: Sphere and horizontal planar segment filters*

— *Part 82: Morphological areal filters: Motif filters*

— *Part 89: Morphological areal filters: Scale space techniques*

Introduction

This part of ISO/TS 16610 is a geometrical product specification (GPS) Technical Specification and is to be regarded as a global GPS Technical Specification (see ISO/TR 14638). It influences the chain links 3 and 5 of all chains of standards.

For more detailed information about the relation of this part of ISO/TS 16610 to the GPS matrix model, see Annex C.

This part of ISO/TS 16610 develops the terminology and concepts for morphological operations and filters, including envelope filters.

Geometrical product specifications (GPS) — Filtration —

Part 40:
Morphological profile filters: Basic concepts

1 Scope

This part of ISO/TS 16610 sets out the basic concepts and terminology for morphological operations and filters, including envelope filters.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14660-1:1999, *Geometrical Product Specifications (GPS) — Geometrical features — Part 1: General terms and definitions*

ISO/TS 16610-1:2006, *Geometrical product specifications (GPS) — Filtration — Part 1: Overview and basic concepts*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14660-1 and ISO/TS 16610-1 and the following apply.

3.1
morphological operation
binary operation involving two sets of geometrical objects, resulting in another geometrical object

NOTE Dilation and erosion are two primary morphological operations, and closing and opening are two secondary morphological operations.

3.2
morphological filter
morphological operation (3.1) that is both **monotonically increasing** (3.11) and **idempotent** (3.12)

3.3
envelope filter
closing (3.10) or **opening** (3.9) filter, whose output envelops the input profile or surface

NOTE A closing filter generates the upper envelope; an opening filter generates the lower envelope.

3.4
Minkowski addition
vector sum of points in two given geometrical sets

3.5
Minkowski subtraction
binary operation defined using **Minkowski addition** (3.4) of two sets

NOTE It is the complement of the Minkowski addition of the complement of the first set with the second set.

3.6
structuring element
⟨morphological filters⟩ second geometrical object used in morphological operations

3.7
dilation
⟨morphological⟩ morphological operation that expands one input set by another

NOTE Dilation is not a morphological filter because it is not idempotent.

3.8
erosion
⟨morphological⟩ morphological operation that shrinks one input set by another

NOTE Erosion is not a morphological filter because it is not idempotent.

3.9
opening
⟨morphological filters⟩ morphological operation obtained by applying the **erosion** (3.8) followed by the **dilation** (3.7)

NOTE An opening is both a morphological filter and one of the two basic building blocks for other morphological filters.

3.10
closing
⟨morphological filters⟩ morphological operation obtained by applying the **dilation** (3.7) followed by the **erosion** (3.8)

NOTE A closing is both a morphological filter and one of the two basic building blocks for other morphological filters.

3.11
monotonically increasing
⟨morphological filters⟩ property of an operation that preserves the set containment condition on its operands

3.12
idempotent
property of an operation such that applying the operation more than once does not change the outcome

3.13
extensive
⟨morphological filters⟩ property of an operation that the output of the operation contains the input

3.14
anti-extensive
⟨morphological filters⟩ property of an operation that the output of an operation is contained in the input

3.15
fill transform
operation that converts a profile into a two-dimensional object, and a surface into a three-dimensional object

3.16
umbra transform
fill transform (3.15) applicable to open profiles and open surfaces

3.17
rigid body transformation
operation on a geometric object involving translations and rotations that do not change the distance between any two points in the object

3.18
rigid motion invariant
property of an operation that does not change under **rigid body transformation** (3.17)

4 Basic concepts

4.1 Minkowski sums

4.1.1 General

Minkowski sums refer to Minkowski additions and Minkowski subtractions involving sets of geometric objects in any dimension. Geometric objects are represented by sets of points.

NOTE A concept diagram for the concepts for morphological filters is given in Annex A. The relationship to the filtration matrix model is given in Annex B.

4.1.2 Minkowski addition

Minkowski addition of two sets, A and B, is denoted $A \oplus B$, and is defined as the vector addition

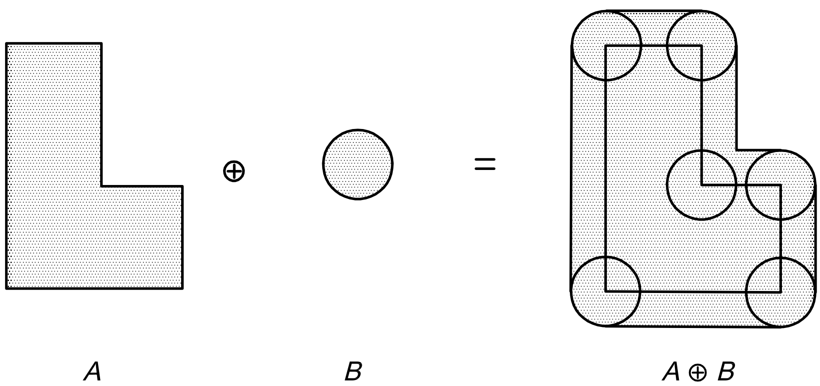
$$A \oplus B = \{a + b : a \in A, b \in B\} \quad (1)$$

Figure 1 illustrates the Minkowski addition of two sets, A and B, in two dimensions.

NOTE 1 Sets A and B can be of any dimensionality. They can also be of mixed dimensionality, e.g. A can be three-dimensional and B can be two-dimensional. Sets in one, two and three dimensions are of interest.

NOTE 2 Minkowski addition can be viewed as the sweep of one set over the other set. This can be seen in the construction of $A \oplus B$ in Figure 1. Minkowski addition leads to an enlargement of the sets that are added.

NOTE 3 Minkowski addition is commutative, i.e. $A \oplus B = B \oplus A$, as can be verified from the definition of Minkowski addition.



NOTE Shaded areas are the sets

Figure 1 — Minkowski addition of two sets

4.1.3 Minkowski subtraction

Minkowski subtraction of set B from set A is denoted $A \ominus B$, and is defined as

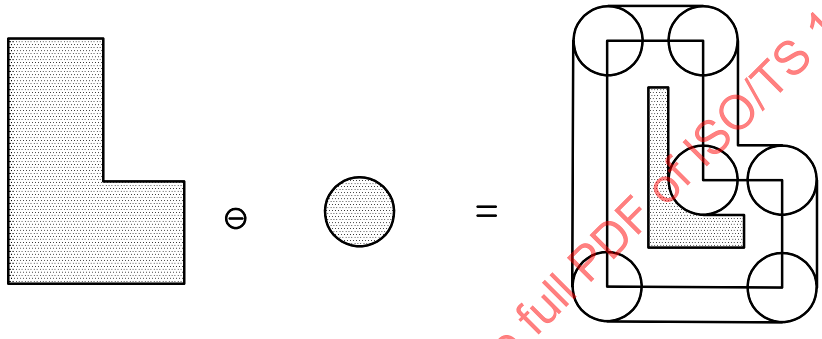
$$A \ominus B = \overline{\overline{A} \oplus B} \tag{2}$$

where the bar denotes complementation. Figure 2 illustrates the Minkowski subtraction of set B from set A in two dimensions.

NOTE 1 As in Minkowski addition, sets A and B can be of any dimensionality. They can also be of mixed dimensionality, e.g. A can be three-dimensional and B can be two-dimensional. Sets in one, two and three dimensions are of interest.

NOTE 2 Minkowski subtraction leads to a reduction of the set A, as shown in the construction of $A \ominus B$ in Figure 2.

NOTE 3 Minkowski subtraction is not commutative, i.e. $A \ominus B$ is not the same as $B \ominus A$.



NOTE Shaded areas are the sets.

Figure 2 — Minkowski subtraction of two sets

4.2 Morphological operations

4.2.1 General

The following morphological operations involving sets A and B are defined using Minkowski sums. It is customary to refer to the set A as the input set and the set B as the structuring element. A symmetric version of the structuring element B is obtained by a reflection of B through the origin of B and is denoted

$$\check{B} = \{-b : b \in B\} \tag{3}$$

The structuring element B shown in Figures 1 and 2 is already symmetrical about its origin; hence $B = \check{B}$ in these cases. It is possible to define two primary morphological operations, called dilation and erosion, and two secondary morphological operations, called opening and closing.

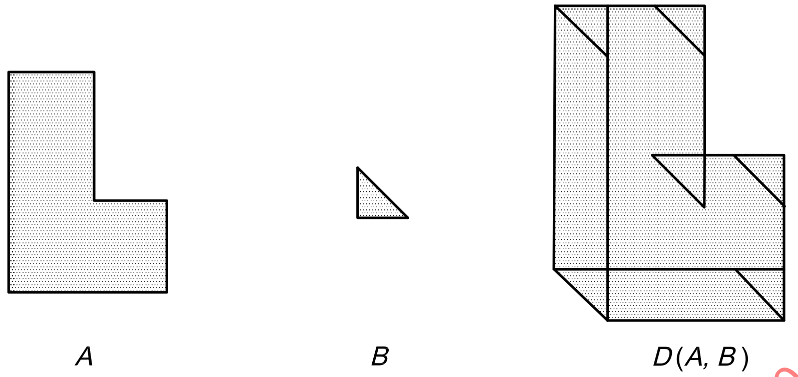
4.2.2 Dilation

Dilation of A by B is defined as

$$D(A, B) = A \oplus \check{B} \tag{4}$$

NOTE 1 Dilation expands the input set A by the structuring element B.

NOTE 2 An example of dilation is shown in Figure 1. Due to the symmetry of B in this example, $D(A,B)$ is the same as $A \oplus B$. An example where B is not symmetric is shown in Figure 3.



NOTE The reference point of the structuring element is the lower left corner.

Figure 3 — Dilation of input set A by a non-symmetric structuring element B

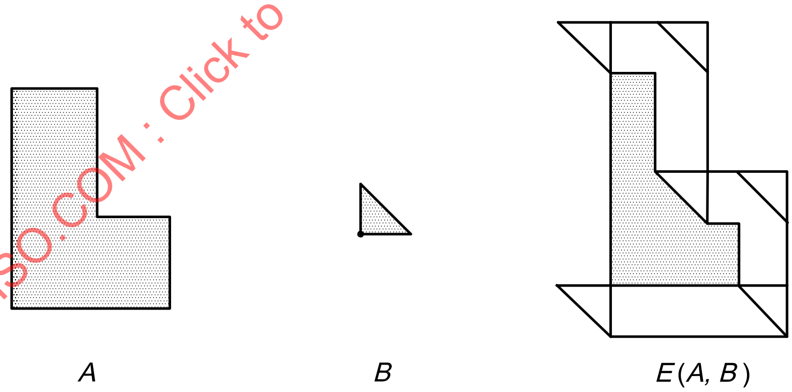
4.2.3 Erosion

Erosion of A by B is defined as

$$E(A,B) = A \ominus \check{B} \tag{5}$$

NOTE 1 Erosion shrinks the input set A by the structuring element B.

NOTE 2 An example of erosion is shown in Figure 2. Due to the symmetry of B in this example, $E(A,B)$ is the same as $A \ominus B$. An example where B is not symmetric is shown in Figure 4.



NOTE The reference point of the structuring element is the lower left corner.

Figure 4 — Erosion of input set A by a non-symmetric structuring element B

4.2.4 Opening

Opening of A by B is defined as

$$O(A,B) = D\left(E(A,B), \check{B}\right) \tag{6}$$

NOTE 1 Opening is obtained by applying the erosion followed by the dilation. The sequence is important. Figure 5 illustrates the opening of A by B in two dimensions.

NOTE 2 Using a round structuring element, such as the one shown in Figure 5, sharp convex corners of the input set A can be rounded.

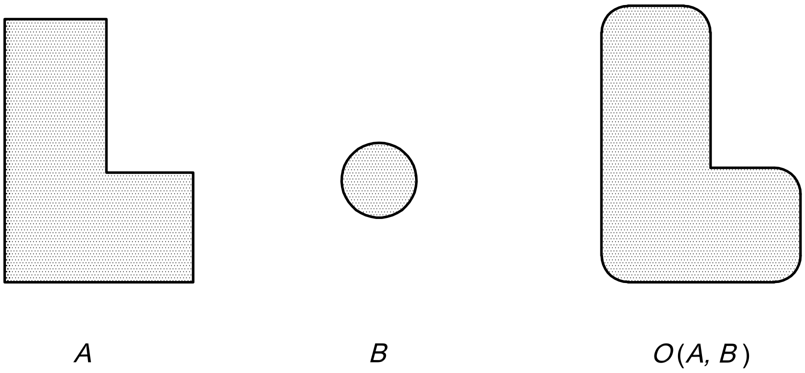


Figure 5 — Opening of input set A by structuring element B

4.2.5 Closing

Closing of A by B is defined as

$$C(A,B) = E\left(D(A,B), \check{B}\right) \tag{7}$$

NOTE 1 Closing is obtained by applying the dilation followed by the erosion. The sequence is important. Figure 6 illustrates the closing of A by B in two dimensions.

NOTE 2 Using a round structuring element, such as the one shown in Figure 6, concave corners of the input set A can be filleted.

NOTE 3 See 5.3 for the relation with envelope filters.

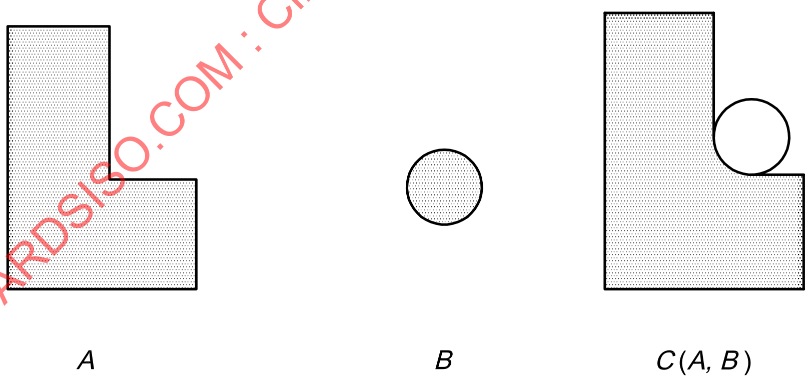


Figure 6 — Closing of input set A by structuring element B

4.2.6 Higher order morphological operations

It is possible to define higher order morphological operations other than closings and openings by combining the dilation and erosion operations in various sequences to obtain different useful results. For example, by applying the operation $O(C(A,B),B)$ on sets A and B of Figure 5, we can obtain both rounding and filleting of the input set A. Examples of higher order morphological operations can be found in ISO/TS 16610-49.

4.2.7 Properties of morphological operations

Morphological operations have several important properties. If $F(A,B)$ denotes a morphological operation where A is the input set and B is the structuring element, then the following properties follow:

a) **rigid motion invariant**: $F(A,B)$ is rigid motion invariant if $tF(A,B) = F(tA,B)$, where t is any rigid body transformation;

b) **monotonically increasing**: $F(A,B)$ increases monotonically if $A_1 \supset A_2$ implies that $F(A_1,B) \supset F(A_2,B)$;

c) **idempotent**: $F(A,B)$ is idempotent if $F[F(A,B), B] = F(A,B)$, i.e. applying the operation more than once does not change the outcome;

d) **extensive/anti-extensive**: $F(A,B)$ is extensive if $F(A,B) \supset A$, and $F(A,B)$ is anti-extensive if $F(A,B) \subset A$.

Table 1 summarises the properties for the four morphological operations defined in 4.2.2 to 4.2.5.

Table 1 — Summary of properties of morphological operations

Property	Dilation	Erosion	Closing	Opening
rigid motion invariant	Yes	Yes	Yes	Yes
monotonically increasing	Yes	Yes	Yes	Yes
idempotent	No	No	Yes	Yes
extensive	Yes	No	Yes	No
anti-extensive	No	Yes	No	Yes

5 Morphological filters

5.1 General

Morphological filters are morphological operations that are monotonically increasing and idempotent. Two types exist:

— opening filters;

— closing filters.

For metrology data processing, the filtering operations are performed on profiles and surfaces. For filtering profiles, the most commonly used structuring elements are circular disks and straight line-segments. For filtering surfaces, the most commonly used structuring elements are spherical balls and rectangular plane-segments.

These structuring elements have the symmetric property such that $B = \check{B}$. To apply the morphological operations developed above for filtering profiles and surfaces, a fill transform is used.

5.2 Fill transform

Fill transforms convert profiles to two-dimensional sets, and surfaces to three-dimensional sets. If the profile or surface is closed, then the fill transform produces the interior region of the closed profile or surface. Figure 7 shows the result of fill transform for a closed profile. If the profile or surface is not closed, then a special fill transform called the umbra transform may be applicable. Figure 8 illustrates the umbra transform with a simple example. In this example, a profile f(x) is defined over a finite interval of x. Its umbra is the entire two-dimensional region under the graph of the function f(x). Similarly, the umbra of a surface f(x,y) is the entire three-dimensional region under the graph of the function.

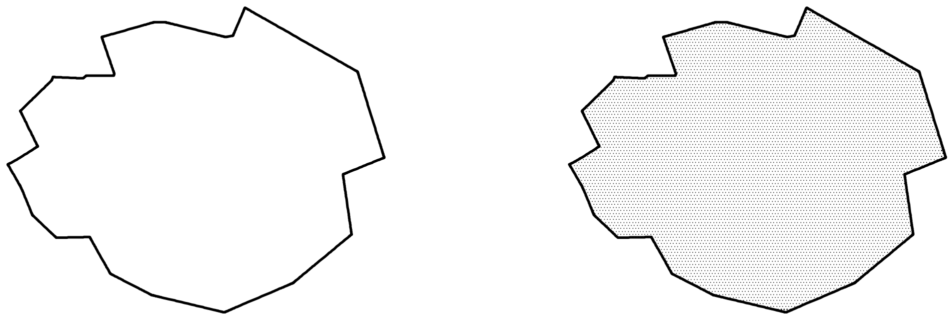
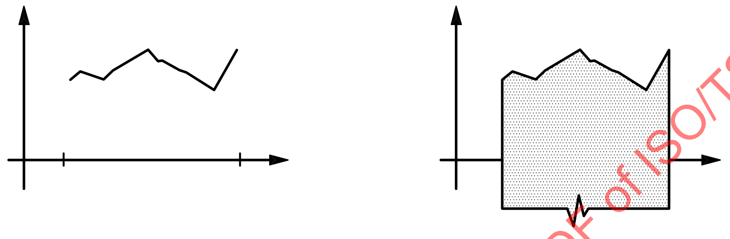


Figure 7 — Fill transform of a closed profile (on the left) to a two-dimensional set (on the right)



NOTE The set on the right, shown shaded, extends downwards to infinity.

Figure 8 — Umbra transform of a profile (on the left) to a two-dimensional set (on the right)

5.3 Discrete morphological filters

Input functions for morphological filters can be either continuous or discrete. If the input is derived from a finite set of points sampled from a surface, as is often the case, it provides a discrete representation of the input function. A continuous function can then be created by an appropriate interpolation of the discrete data.

Discrete morphological filters are morphological filters that take discrete representations of the input function and the structuring element, and output a discrete representation of the filtered result. Efficient algorithms are available to implement the discrete versions of dilation, erosion, opening and closing filters.

Figure 9 shows the input and output profiles of a discrete dilation filter.

Figure 10 shows the input and output profiles of a discrete erosion filter. If the input represents the discrete sampled data of the locus of the centre of a round stylus, then the output of the erosion filter can be the approximate representation of the underlying surface.

Figure 11 shows the input and output profiles of a discrete opening filter.

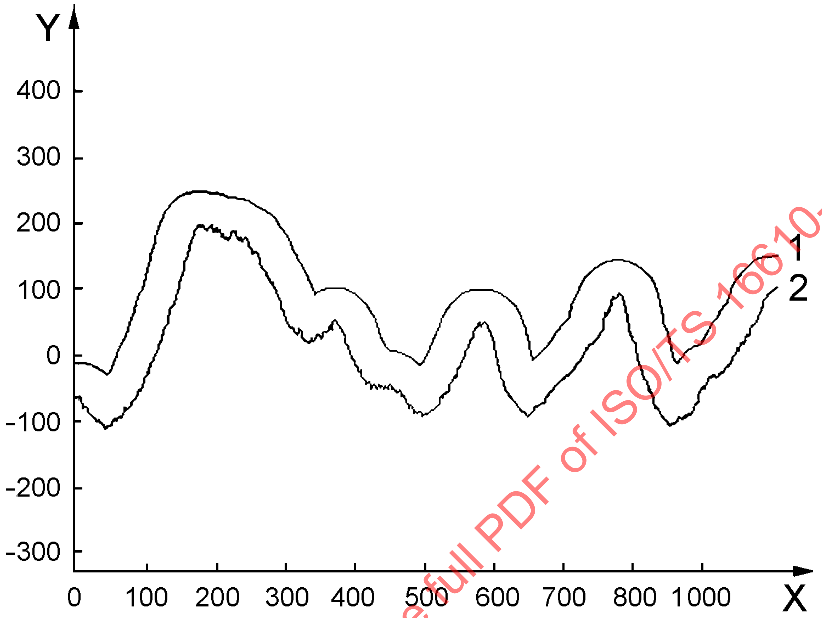
Figure 12 shows the input and output profiles of a discrete closing filter. It leads directly to the envelope filter.

5.4 Envelope filters

An example of envelope filter is shown in Figure 12. The input profile (the bottom line in Figure 12) is enveloped using a circular disk of finite radius to produce the output profile (the top line in Figure 12). From Table 1 it can be seen that, irrespective of the type of structuring element used, the envelope filters are rigid motion invariant, monotonically increasing, idempotent and extensive.

5.5 Sampling and reconstruction

Discrete morphological operations and filters are applied on sampled data. There is no theorem for morphological operations and filters equivalent to the Nyquist theorem, i.e. for morphological operations and filters, no universal equidistant sampling can be found which has no loss of information. Instead there are a number of morphological sampling theorems, which limit the amount of information that is lost. Details on sampling and reconstruction for morphological operations can be found in ISO/TS 14406.



Key

X distance, µm

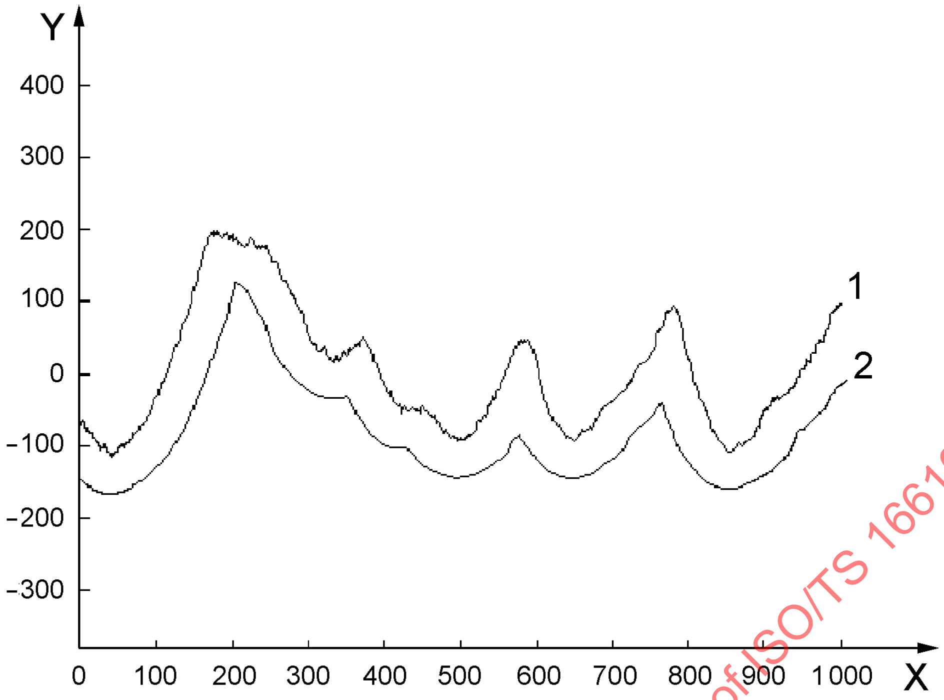
Y height, µm

1 filtered result

2 input function

NOTE The input function is sampled at 0,5 µm intervals. The structuring element is a circular disk of 50 µm radius. The filtered result is shown above the input function.

Figure 9 — Discrete dilation filter



Key

X distance, µm

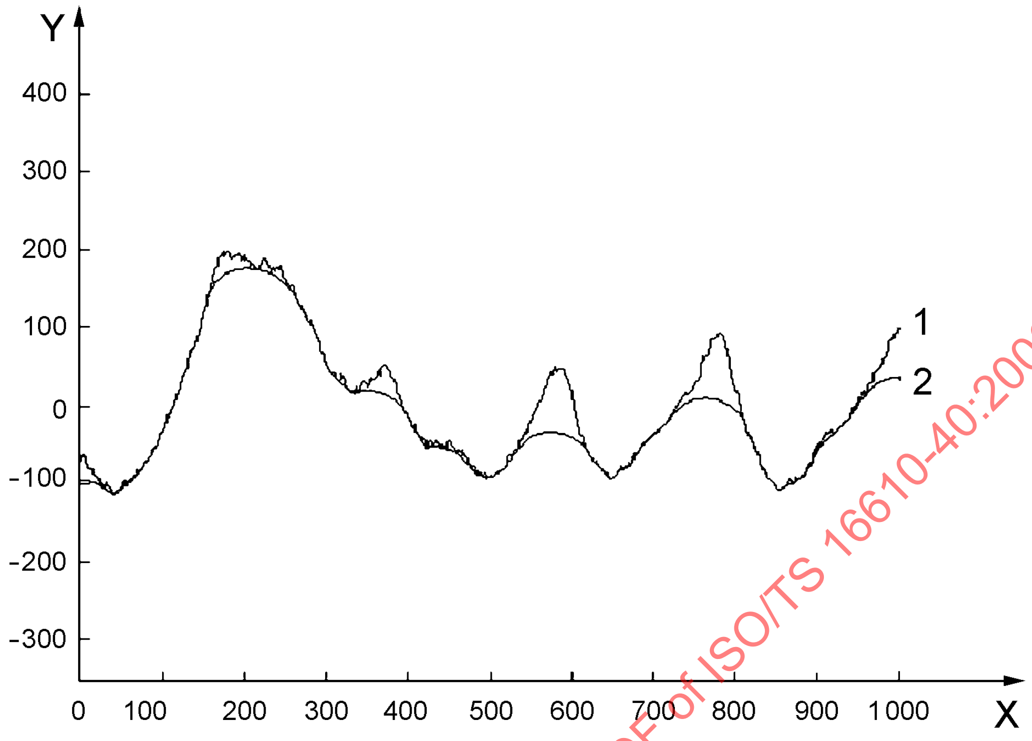
Y height, µm

1 input function

2 filtered result

NOTE The input function is sampled at 0,5 µm intervals. The structuring element is a circular disk of 50 µm radius. The filtered result is shown below the input function.

Figure 10 — Discrete erosion filter



Key

X distance, µm

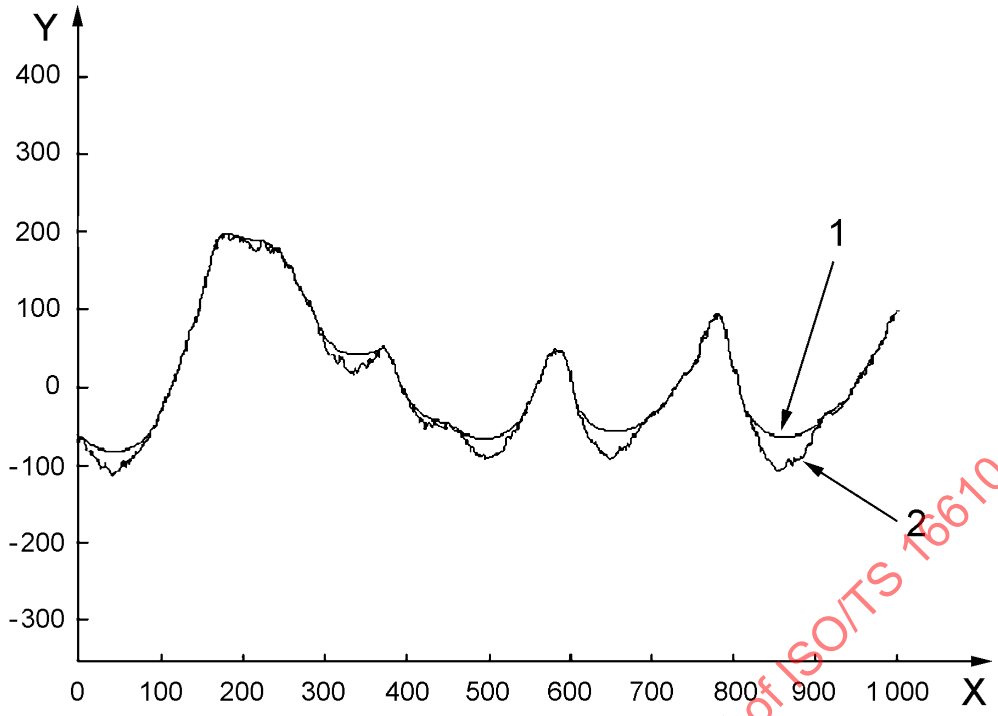
Y height, µm

1 input function

2 filtered result

NOTE The input function is sampled at 0,5 µm intervals. The structuring element is a circular disk of 50 µm radius. The filtered result is shown below the input function.

Figure 11 — Discrete opening filter



Key

X distance, µm

Y height, µm

1 filtered result

2 input function

NOTE The input function is sampled at 0,5 µm intervals. The structuring element is a circular disk of 50 µm radius. The filtered result is shown above the input function.

Figure 12 — Discrete closing filter

Annex A
(informative)

Concept diagram

The following is a concept diagram for this part of ISO/TS 16610.